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THE SCIENCE AND APPLICATIONS TETHERED PLATFORM (SATP) PROJECT

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## THE SCIENCE AND APPLICATIONS TETHERED PLATFORM (SATP) PROJECT

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### Background

The capabilities of tether systems in orbit are going to be demonstrated by the first three planned flights of the Tethered Satellite System (TSS), a joint US-Italian project now in the advanced development stage. As is well known, these test flights will investigate the properties of tether systems as low-altitude atmospheric research facilities and as electric power generators.

Many more applications of tethers have been proposed in the years since the ideas of the late G. Colombo started to circulate in the space community, some of which may be realized on the planned Space Station. In fact, applications of tethers to the Space Station, for both Space Station initial configuration and later extension of Space Station capabilities, are already the subject of a number of studies being performed both in the US and in Italy on the initiative of NASA and the Italian Space Agency/National Space Plan (PSN). Such studies are being conducted separately, with the purpose of testing a variety of concepts and approaches. A comparative analysis of results will allow the choosing of the most promising ideas for further development. The broad range of applications presently under study includes applications in electrodynamics, transportation, microgravity in addition to basic research.

Concerning the studies performed in Italy, PSN has decided to concentrate effort on those applications that show promise of an early use on the Space Station. The guidelines issued by PSN in its award to Aeritalia call for emphasis on two main subjects:

- a Science and Applications Tethered Platform (SATP), as a general-purpose, reconfigurable support for experimentation in science and technology; and
- a Tethered Teleoperator Manoeuvring System (TTMS), as a basic tool for a variety of operational uses ranging from payload launch and retrieval to Shuttle docking.

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The main thrust of the Aeritalia effort (80%) is to be devoted to the SATP Definition Study; the remaining 20% is to be devoted to an analytical study of the teleoperator concept leading to a feasibility assessment. Basic science applications are to take precedence over technological applications.

The SATP Definition Study is divided in two phases, the first devoted to assessment of applications and selection of the most promising of them, and the second to preliminary system design. An important part of the Study is identification of goals and requirements, and later design, of a functional scaled down replica of SATP to be used for testing the fundamental features of SATP on a dedicated Shuttle flight. At the end of the first study phase, recommendations will be submitted to PSN concerning the demonstration mission.

According to the initial concept, the SATP platform is to be located in one of the two stable libration points along the orbit radial direction. The tether may be up to 20 km long. Platform design should aim at modularity with a resources module including power, communication, attitude and thermal control and data handling subsystems, and a payload module for the experimental apparatus. Platform mass may be up to 50 tons and provisions should be made such that experiments lasting several months without interruption may be accommodated.

#### Inquiry on interests and requirements of potential SATP users

Since the main user of SATP will be the scientific community, it was determined important to start our study with an inquiry directed to potential users. As a first step, a "Call for Ideas" questionnaire was sent between March and April 1985 to some 200 representatives of selected scientific institutions in the USA and Europe.

It was realized from the start that this inquiry would require a long time in order to produce a level of detail in potential user proposals such that decisions could be based on them, with repeated rounds of interaction between Aeritalia and the addressees expected. However, only a period of eight months was available for the phase of the Definition Study leading to a selection among competing options. A compromise solution was found as follows. First, it was decided that the bulk of addressees should be chosen from among people already well acquainted with the properties of tether systems (in effect, all those having submitted proposals for the TSS payloads), so that learning time would be reduced to a minimum. As a second step, it was decided to immediately start study of those applications that, in the opinion of the study team, offered the most promise for SATP use, even though confirmation of the validity of choices

would come only later. The ideas selected for initial study were: (1) a tethered platform for microgravity research, and (2) an astronomical observation platform requiring precise pointing.

Results of the inquiry. Response to the "Call for Ideas" has been encouraging, considering the limited audience selected and the short time available, with about 20 % returns to date. The most promising suggestions received are listed in Table 1. Communication with respondees is in progress in order to gain a better understanding of the requirements posed by the proposals.

Our initial assumption of a keen interest in the SATP project by the microgravity science community has been confirmed by the first round of contacts with potential users. This is evident from the quality and number of propo-

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Microgravity & Materials Science

Biotechnology  
Organic & Inorganic Crystal Growth  
Radiobiology  
Pharmaceutical Production  
Measurement of Chemical Reaction Rate Constants  
Scattering of Molecular Beams  
Environmental Effects on Chemical Reactions & Macromolecules  
Diffusion & Convection Phenomena

Plasma Physics & Electrodynamics

Electron Distribution of Ionospheric Plasma  
Plasma Wave Propagation  
Active Beam-Plasma Interaction  
Mapping of Thermal Plasma Motion  
Particle-Plasma Interaction  
Power Generation

Geophysics & Atmospheric Physics

Cosmic Dust Collection  
Simulation of Planetary Environments  
Earth Observation by High-Resolution Solid-State Sensors  
Geomagnetic Field Mapping  
Crustal/Core Geomagnetic Field Anomaly Mapping  
Measurement of Electric Fields in the Atmosphere (Thunderstorms)  
Interplanetary Medium - Solar-Terrestrial Relationship

Table 1. Summary of Proposals for SATP Application from "Call for Ideas".

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sals, some of them actually coming from groups of scientists with interests in several disciplines. The stated reasons for such interest include:

- the large number of opportunities for investigators offered by a permanent facility;
- the availability of high power;
- the good projected quality of the environment, both from the point of view of dynamical stability and of freedom from contamination; and
- the inherent capability of tether systems of providing, if required, a gravity field variable both in magnitude (within a range limited by tether length) and in direction.

Response from the astronomy and astrophysics community has been limited thus far. Present-day and planned free-flying observatories appear adequate for the needs of these disciplines, whereas the advantages of a tether system for such applications is not as clear as for microgravity. Investigation of this application is nevertheless continuing, in the hope that once the capabilities of the system for stabilization and filtering of dynamical disturbances have been demonstrated, astronomers and astrophysicists will reconsider SATP value.

A considerable number of proposals concerns Earth and Planetary Physics and the Physics of the Atmosphere. Yet another group of proposals concerns applications of the electrodynamic tether. Many of them are similar to or develop ideas already submitted for TSS. However they would benefit from longer experiment times offered by SATP and the exploration of a region of space different from that accessible to the Shuttle. Since the selection of applications for the proof-of-concept Shuttle flight is the more urgent study task, and since proof of the electrodynamic tether concept is already the subject of TSS flights 1 and 3, applications requiring a conducting tether have been assigned a lower priority in the early part of the SATP study. However, further study will be devoted to them with the intent of making a separate proposal for electrodynamic systems including power generation.

#### System Studies

Independent of the issue of possible uses of SATP, a number of fundamental problems have to be investigated in order to assess the feasibility and usefulness of a tether system as a permanent facility on the Space Station. These concern the issue of lifetime and reliability of the system as a whole; the impacts of the tether system on the Space Station; and

the sharing of resources between Station and SATP Platform.

Space Environment Problems. The lifetime of the tether system in orbit depends on the impact rate of meteorites and debris on the tether and on the degradation rate of tether construction materials under exposure to ionospheric atomic oxygen. Estimates of the impact probability are complicated by the considerable uncertainty in the actual and projected meteorites and debris flux. In addition, results are dependent on the way tether damage is modelled. According to the current models, man-made debris is the most important source of tether impact hazards for a 500-km orbit and a tether of 0.5 cm or larger diameter (Ref.1). Preliminary calculations lead to an estimated lifetime as low as 0.5 years for a single-strand aluminum tether of 1 cm diameter at a 95 percent probability level. Lifetimes longer by about a factor 3 are obtained for metals such as copper (Ref.2). Although model uncertainties might easily lead to calculated lifetimes differing by 2 orders of magnitude or more (Ref.3), such results do point to a fundamental problem that has to be investigated in detail before long-duration tether experiments are initiated. Regarding degradation, the corrosive effect of atomic oxygen on synthetic materials such as Kevlar and Kapton are well known. Possible solutions now being studied include metal coating and alternative tether materials. The results of the tether lifetime study will lead to recommendations for optimal tether diameter and composition, with impacts on system parameters such as tether mass and maximum length and hence techniques for carrying it into orbit and deploying.

Tether Systems for Space Station. An early assessment of the impact of a tether system on the Space Station is necessary in order that the Space Station retains the flexibility of employing tethers in its present design and later extension. The main areas of concern include displacement of the center of gravity of the Space Station complex, added drag and hindrance to visual observations and to operations by the STS and OMV in the proximity of the Station. None of these problems appears insurmountable if the possibility of housing tethers is taken into account in Space Station design from the start.

Resources Sharing. The extent to which SATP can be considered a user of Space Station resources, rather than providing for its own needs, is very important for SATP design. Transfer of power and data through the tether, if feasible, could lead to considerable simplification of system and subsystem design. Therefore studies have been initiated at Aerialia on the use of the tether as a power line and as a communication link with optical fibers. Considerations include tether technology, safety, reliability and compatibility with the primary scientific uses of SATP.

The outcome of the activities so far described is expected

to lead to the sizing of SATP and to establishing system technical requirements.

### The Elevator System

Although the guidelines of the PSN award to Aeritalia call for a general-purpose platform, concept developments up to now have led to specialized designs for microgravity, precise pointing and electrodynamic applications. The issue of mutual compatibility of applications will be addressed when the requirements for each application are established to a sufficient level of detail.

In addition to cleanliness and high power, the requirements of microgravity applications call for a very stable dynamical environment with residual acceleration much smaller than  $10^{-5}$  g as well as the possibility of modulating the gravity level or of obtaining differential measurements at locations with different gravity levels. This has led to the consideration of a moving Elevator along a tether deployed to a fixed length. Such a system has already been proposed as a solution to the complex control problems associated with retrieval of the entire tether system (Ref. 4).

Since radial acceleration changes with position along the tether (at a rate of approximately  $3.7 \times 10^{-4}$  g per km of distance from center of gravity), the Elevator would be able to attain residual gravity levels different from zero. The minimum residual acceleration is attained with the mobile laboratory located in the Space Station - Tether System orbit center (the point where gravity exactly balances centrifugal acceleration).

After consideration of sources of dynamical disturbances, a reasonable design objective appears to be attainment of an acceleration upper limit of  $10^{-8}$  g. The residual acceleration is mostly due to the harmonics of the Earth gravity field, to residual librations and to thermal longitudinal oscillations. The attainment of such a goal is dependent on the control of libration amplitudes to less than  $10^{-3}$  radians and effective insulation of the microgravity facility from disturbances originating in the Space Station and propagating along the tether.

Investigation of the Elevator concept at Aeritalia is continuing, including configuration studies and Elevator translation methods.

### The Pointing Platform

The idea of using the gravity gradient tension in the tether to provide two-degree-of-freedom attitude control of a pointing platform originates with a proposal by L.G.Lemke of

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NASA Ames Research Center (Ref. 5). The natural orientation of the tether system along the vertical makes it suitable not only for Earth observation purposes, but also for astronomical observations if SATP platform were endowed with an independent capability for changing pointing direction away from the vertical. As with other possible SATP applications, such an observatory would take advantage of the facilities of the Station for maintenance and repair while being isolated from contamination and mechanical disturbances.

The pointing platform concept relies on the tether tension itself to provide a restoring torque against disturbances via displacement of the SATP attachment point. In principle, this provides the ability to control disturbances coming from libration and displacements of the center of gravity aboard the platform. Computer simulation of the control in an idealized case assuming perfect mechanism response and error-free attitude measurement shows that stabilization within arcsecond magnitude can, in principle, be achieved on an actual system.

From a technological point of view the problem is to handle even the most minute disturbances by means of a relatively strong force such as tension, so as to satisfy the tight accuracy requirements of a fine-pointing application. The areas of present investigation include design of the movable attachment mechanism, identification of a robust control law allowing for sensor and hardware errors, and hardware definition.

#### The Demonstration program

The first phase of the SATP Definition Study will end with recommendations toward development of a Shuttle flight test of the performance of the basic features of SATP. The demonstration should provide the confidence needed to initiate a full-scale effort devoted to implementation of a tethered platform on the Space Station. The test flight could be scheduled as early as 1989.

Both cost and schedule constraints impose a necessity to re-use to the maximum possible extent the hardware already under development for the STS-based TSS flights. In particular, use of the same deployer is mandatory. Therefore the demonstration should be a proof-of-concept rather than a full test of SATP in a down-scaled configuration.

Progress of the Aeritalia work so far indicates that the demonstration may concern two concepts:

- a demonstration of the elevator as a means of achieving a residual acceleration field at center of force suitable for the microgravity-lab application; and

- a demonstration of the SATP movable attachment point concept for the fine pointing application.

Regarding the microgravity application, one is mainly concerned with perturbing accelerations and disturbances propagating along the tether. These are originated mainly by the Space Station and by Elevator motion. Disturbances coming from these sources excite vibrations with a rate of damping increasing with frequency, but also a series of resonances with peaks not easily modelled because of the complexity of phenomena involved. Another unknown in the problem is the magnitude of the expected natural damping and/or what methods could be used for actively attenuating the disturbances. A Shuttle test of an Elevator model would therefore be valuable for studying such phenomena, evaluating the effects and testing on the field practical disturbance suppression techniques.

Concerning the fine-pointing application, the demonstration will address attitude motion and libration-control properties of the movable attachment point concept. The main problem of this new means of attitude stabilization is devising suitable control techniques when system dynamics as complex as those outlined above are present. Tether tension represents both the control force and the major source of disturbances. The control system must be able to neutralize tether disturbances and to provide the small control torque needed to counteract external perturbations. The control strategy could be of a double-loop type. Hardware and software optimization would benefit from an on-orbit test due to the complexity of the overall system dynamics.

One fundamental issue concerns the extent to which a demonstration mission of a scaled down SATP with the Shuttle in the usual 300-km orbit constitutes proof-of-concept of a full-scale mission in a 500-km orbit. Similarity theory requires identification of suitable dimensionless parameters characteristic of each physical aspect one wants to model, and scaling such that those parameters are left unchanged. In practice, implementation of full or partial similarity conditions may prove unpractical or unfeasible. Even in this case, a STS flight test would be significant as a means of validating the mathematical model describing the dynamics and control, by comparison between predicted and actual system behaviour.

## Conclusions

The SATP Project Definition Study is now about midway through its first phase. The analyses conducted up to now have led to an appraisal of users interest in the project and to a deeper understanding of the problems associated with large, long-lived tether systems in space. In addition, two specialized platform designs, devoted to microgravity and

precise pointing applications, are being studied because of their potential usefulness and the promise of technical feasibility.

The second phase of the Definition Study will mainly be concerned with developing configuration options for a Shuttle-based demonstration flight devoted to the validation of the above mentioned specialized platform designs. Further development, subject to a positive decision on the continuation of the project by NASA and the Italian Space Agency, may lead to the realization of such a flight as early as 1989.

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